Community Benchmark Problem for Intelligent Contingency Management

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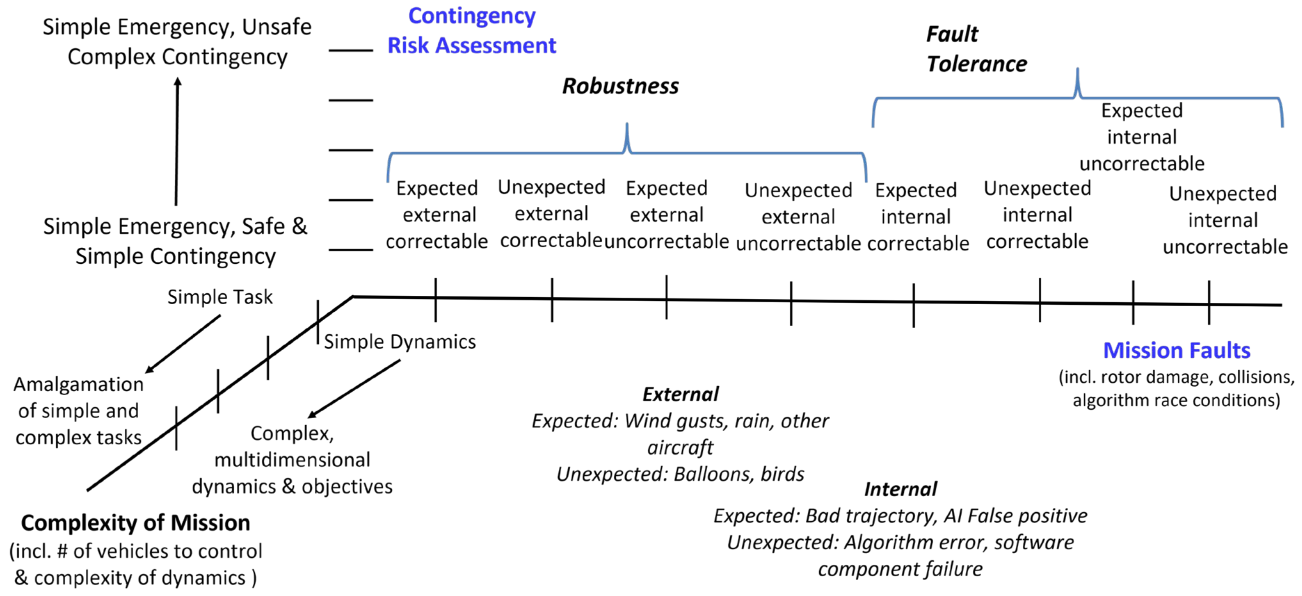
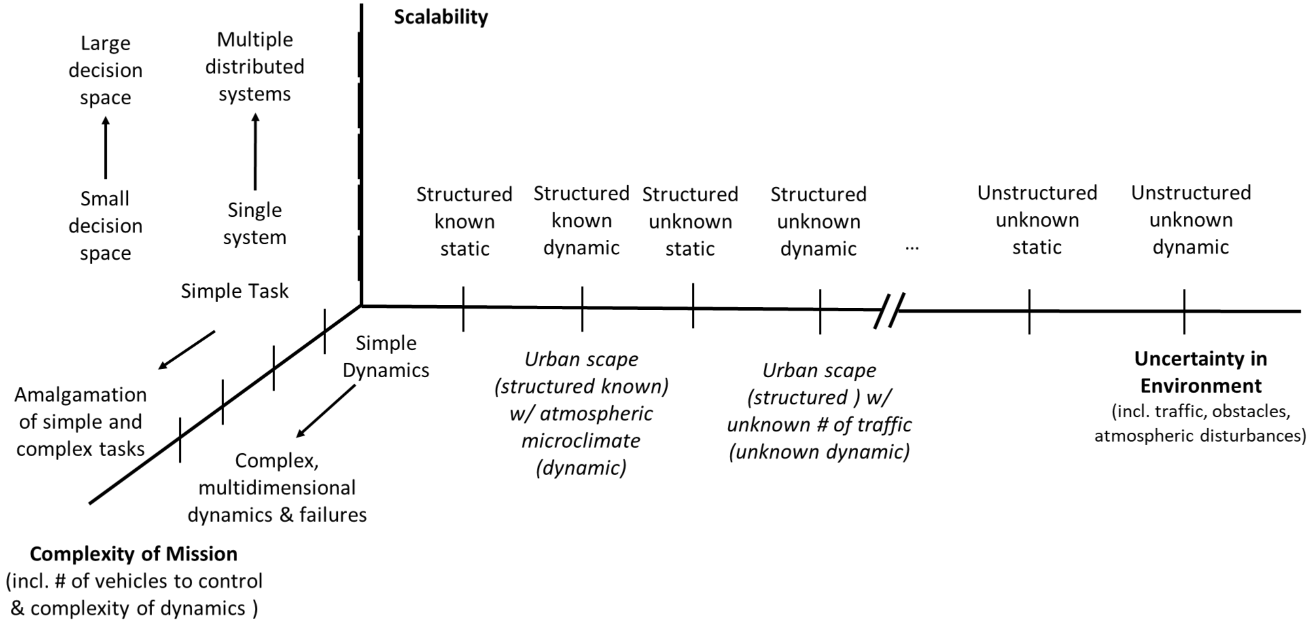
Community Benchmark Problem

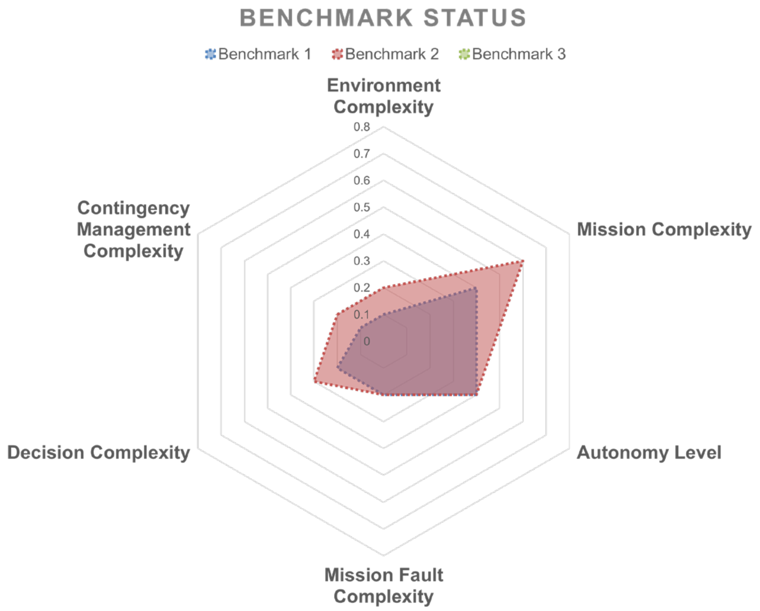
- **Goal:** Engage the broader community in addressing and overcoming inherent challenges related to the maturation of organizations and capabilities within the UAM sector.
- **Unique Approach:** Combination of UL 4600 and CMMI-DEV methodologies for enhanced safety and process maturity in UAM.
- **New and Different:** Emphasis on scoring, tracking, and real-world application in UAM scenarios over time, sustainable over the life of a UAM organization/project.
- **Impact of Success:** Enable the community to move toward consensus on maturing UAM, influencing future technology, policies, and urban transportation systems.
- **Stakeholders:** Beneficial to a wide range of audiences from tech developers to the general public.

Background

- Establish a scoring mechanism for tracking progress for the ICM sub-project annual benchmark exercise
  - How much have we advanced in autonomy? In modeling faults? In environmental complexity? Etc.
- There are many, many metrics that can be tracked
- As we publish our own simulator and more experiments, how does the public compare in its improvements?







Background

NASA/CR—2020–5001587

Urban Air Mobility Operational Concept (OpsCon) Passenger-Carrying Operations

George Price, Douglas Helton
Crown Consulting, Inc., Arlington, Virginia

Kyle Jenkins, Mike Kvicala, Steve Parker, Russell Wolfe
Modern Technology Solutions, Inc., Alexandria Virginia

Prepared under contract# GS-00F-038DA

Concept of Operations

v2.0

Foundational Principles

Roles and Responsibilities

Scenarios and Operational Threads

NASA/TM–20210019876

UAM Airspace Research Roadmap

Ian Levitt and Nipa Phojanamongkolkij
Langley Research Center, Hampton, Virginia

Kevin Witzberger, Joseph Rios, and Annie Cheng
Ames Research Center, Moffett Field, California

Description of the NASA Urban Air Mobility Maturity Level (UML) Scale

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NASA Ames Research Center, Moffett Field, CA, 94035, USA

As part of its assessment of the nascent passenger-carrying urban air mobility (UAM) ecosystem, NASA's UAM Coordination and Assessment Team developed a framework known as the UAM Maturity Level (UML) scale. This framework is intended to have multiple applications including: 1) insight into the likely operational capabilities as a UAM air transportation system develops over time; 2) analysis of technology and regulatory requirements associated with the UAM maturation process; 3) assessment of the current maturity of various segments of the UAM ecosystem; 4) coordination of UAM ecosystem priorities and areas of emphasis; and 5) increasing community and public awareness of UAM and how it may affect mobility in the future. This paper describes the structure of the UML scale and its levels. The paper also describes candidate strategies for advancing between levels, along with associated regulatory gaps and considerations.

Methodology

Mission Complexity

Environment
Mission Operations
Autonomy
Decision-Making
Mission Fault

How do I understand this UAM Framework's capability (systems and processes) in ensuring the safety of complex missions?

UL 4600 Assessment

Mission Risk Acceptability

Contingency Management
Mission Success
Operational
Mission Redefinition
Environment (Area/Population/Conditions)

How much risk am I willing to accept for a mission under this UAM Framework?

CMMI-DEV Assessment

UL 4600 Case Evidence

Measure UAM Capability and Organizational Maturity Criteria over time

Mission Complexity

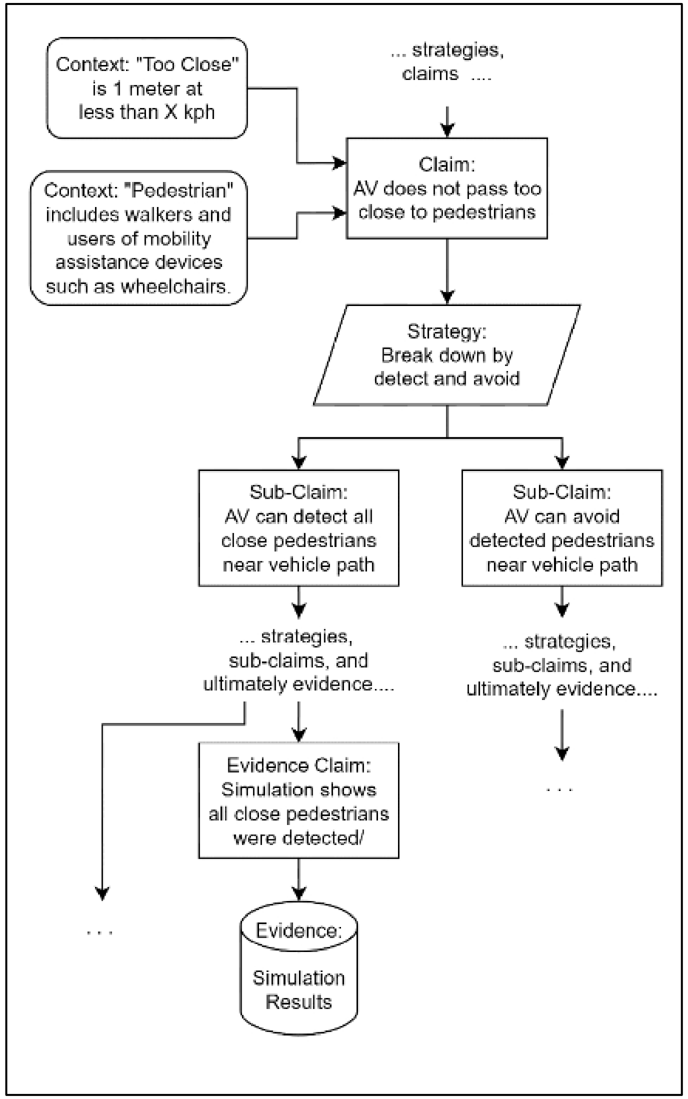
How do I understand this UAM Framework's capability (systems and processes) in ensuring the safety of complex missions?

Methodology

For each Mission Complexity Category

1. **Craft a UL 4600 Safety Case**

SCAN ME



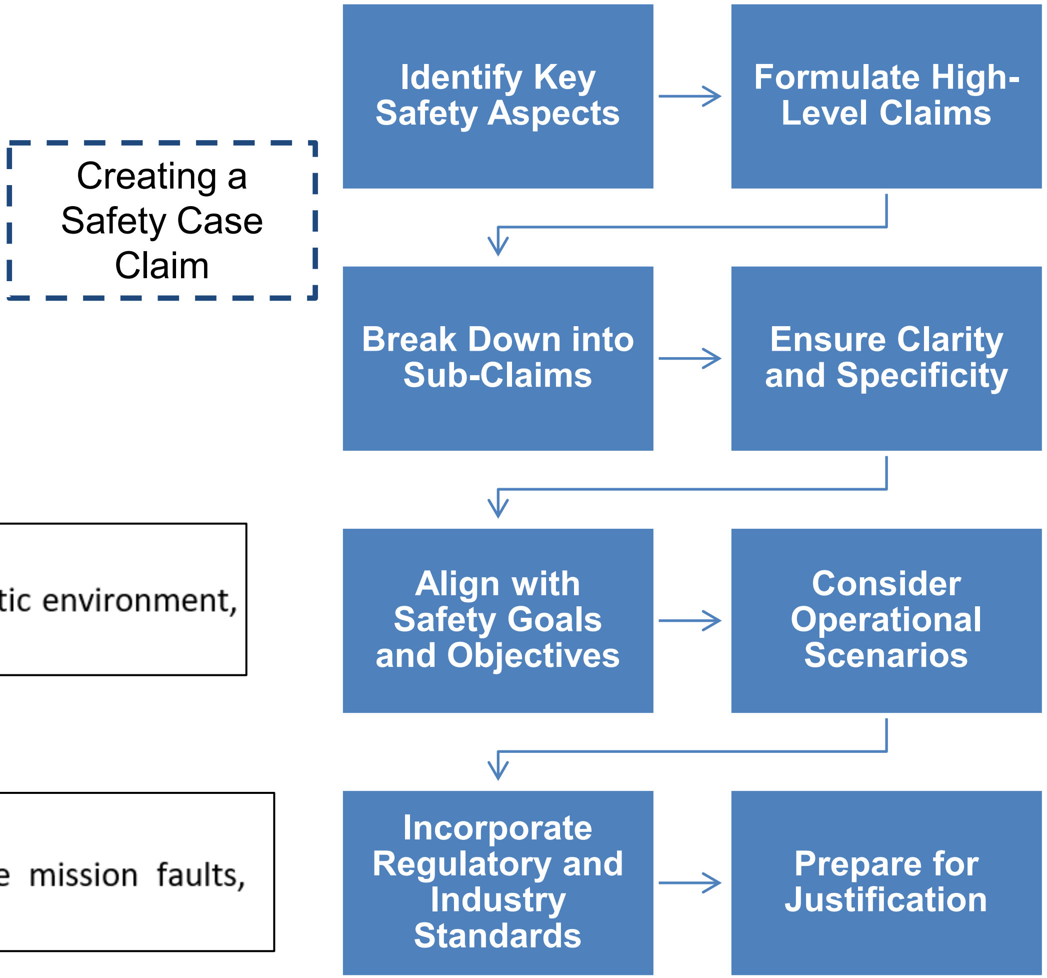
Safety Case Construction: UL 4600 emphasizes the development of a comprehensive safety case for autonomous systems, detailing how safety is achieved and maintained.
Technology-Neutral: The standard is designed to apply to a wide range of technologies and autonomous systems, not limited to specific types or use cases.
Risk Analysis: Includes methodologies for identifying, assessing, and mitigating risks associated with autonomous operations.
Autonomy Validation: Focuses on the validation processes for ensuring that autonomous systems perform safely under a wide range of conditions.
Human-System Interaction: Addresses how autonomous systems interact with humans, including operators, users, and other stakeholders.

Methodology

For each Mission Complexity Category

1. Craft a UL 4600 Safety Case

   a) **Create a claim that the UAM Framework meets the standards of the Mission Complexity Category**



Structured, Known, Static Environment

Claim 1: The UAM Framework reliably simulates or emulates a Structured, Known, Static environment, aligning with established theoretical parameters and controlled conditions.

Expected, External, Correctable Mission Fault

Claim 5: The UAM Framework effectively manages Expected, External, Correctable mission faults, demonstrating resilience and adaptability in urban air mobility operations.

Methodology

For each Mission Complexity Category

1. Craft a UL 4600 Safety Case
   a) Create a claim that the UAM Framework meets the standards of the Mission Complexity Category
   b) Create sub-claims S to support the Claim

Complexity of Environment

- Structured/Unstructured
- Known/Unknown
- Static/Dynamic

Complexity of Mission Operations

- Simple vs Complex Flight Plan
- Simple vs. Complex Flight Tasks
- Normal vs. Abnormal Operations
- Recoverable vs. Unrecoverable Failures
- Fundamental vs. Advanced Handling and Flight Quality

Complexity of Autonomy

- Manual Control
- Flight Stability
- Envelope Protection
- Navigation and Collision Avoidance
- Conditional Automation
- Conditional Automation with AI
- High Automation
- Full Automation:

Complexity of Decision-Making

- Mission-level.
- Task-level
- Plan-level
- Maneuver-level
- Control-level
- Health-level .
- Fault-level
- Recovery-level

Complexity of Mission Faults

- Expected/Unexpected
- External/Internal
- Correctable/Uncorrectable

Methodology

For each Mission Complexity Category

1. Craft a UL 4600 Safety Case
   a) Create a claim that the UAM Framework meets the standards of the Mission Complexity Category
   b) Create sub-claims S to support the Claim
   c) **Define, at a minimum:**
      - **Evidence**
      - **Performance Targets**
      - **Safety Performance Indicators**
      - **Methodology**

Sub-Claim 3.7: High Automation

Sub-Claim: The UAM Framework achieves high automation, allowing aircraft to operate autonomously in a wide range of scenarios. The human operator's role is relegated to system monitoring, with intervention only needed in rare cases of system failure or unexpected operational conditions.

Evidence

1. **Advanced Autonomous Operation Systems:** Implementation of highly advanced autonomous systems capable of handling all aspects of flight operations in designated scenarios without human input.
2. **Sophisticated Monitoring and Alert Systems:** Integration of state-of-the-art monitoring systems that alert operators to system anomalies or failures, enabling rapid human intervention when necessary.
3. **Fail-Safe Mechanisms:** Robust fail-safe mechanisms that ensure safe operation even in the event of system failures or other exceptional circumstances.
4. **Real-Time System Health Monitoring:** Continuous monitoring of system health and performance, with capabilities to predict potential issues before they arise.

Performance Targets

- Autonomous operation success rate of over 99% within operational domains.
- System anomaly detection and alerting accuracy of 100%, with operator intervention time under 1 minute.
- Fail-safe mechanisms to engage correctly in 100% of test scenarios involving system failures or anomalies.

Safety Performance Indicators (SPIs)

1. **Autonomy Reliability and Independence:** Evaluate the reliability of the autonomous systems in maintaining safe and efficient operations without human intervention.
2. **Effectiveness of Monitoring and Alert Systems:** Assess the accuracy and timeliness of the monitoring systems in detecting system anomalies and alerting operators.
3. **Fail-Safe System Performance:** Measure the effectiveness and reliability of fail-safe mechanisms in ensuring safety during system failures or unexpected conditions.

Methodology

1. **Comprehensive Autonomous System Testing:** Extensive testing in a variety of scenarios to ensure robust and reliable autonomous operations.
2. **Monitoring System Validation:** Rigorous testing and validation of monitoring and alert systems to ensure accurate and timely detection of anomalies.
3. **Fail-Safe Mechanism Testing:** Systematic testing of fail-safe mechanisms under simulated failure conditions to confirm their reliability and effectiveness.

Methodology

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      - Evidence
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      - Safety Performance Indicators
      - Indicators
2. **Perform CMMI-DEV Analysis: $\forall s \in S$, let E be the defined Evidence and P be the CMMI-DEV Process Areas for an organization. Then $\forall e \in E$,**
   a) **Identify relevant Process Areas $p \subseteq P$**
   b) **$\forall \varphi \in p$, Appraise CMMI-DEV Capability Level**

CMMI-DEV Capability Levels

Level 0: Incomplete
- Process not performed or only partially performed.
- Specific goals of the process area are not satisfied.

Level 1: Performed
- The process accomplishes the necessary work.
- Specific goals of the process area are satisfied.

Level 2: Managed
- The process is planned and executed according to policy.
- Involves relevant stakeholders and is monitored and reviewed.

Level 3: Defined
- Process is tailored from the organization's set of standard processes.
- Contributes experiences to the organizational process assets.

Project Management Practice Group	Engineering Practice Group	Process Management Practice Group	Support Practice Group	High Maturity Practice Group
PP	MA	OPF	PPQA	OPP
PMC	REQM	OPD	CM	QPM
RSKM	RD	OT		
SAM	TS			
	PI			
	VAL			

Example of Organizational Practice Groups

Acronym	CMMI-DEV Process Area
CAR	Causal Analysis & Resolution
CM	Configuration Management
DAR	Decision Analysis & Resolution
IPM	Integrated Project Management
MA	Measurement & Analysis
OID	Organizational Innovation & Deployment
OPD	Organizational Process Definition
OPF	Organizational Process Focus
OPP	Organizational Process Performance
OT	Organizational Training
PI	Product Integration
PMC	Project Monitoring & Control
PP	Project Planning
PPQA	Process & Product Quality Assurance
QPM	Quantitative Project Management
RD	Requirements Definition
REQM	Requirements Management
RSKM	Risk Management
SAM	Supplier Agreement Management
TS	Technical Solution
VER	Verification
VAL	Validation

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3. **Use capability level as score and average across all evidence for each sub-claim**
4. **Integrate Findings into Next Benchmark Evaluation and new Safety Cases**

Results

Benchmark 1		Benchmark 2		Benchmark 3	
Complexity Category	***Sub-Claims***	***Complexity Category***	***Sub-Claims***	***Complexity Category***	***Sub-Claims***
Environment	Structured, Known, Static	Environment	Structured, Known, Dynamic	Environment	Structured, Known, Dynamic
Mission Operations	Simple Flight Plan, Simple Flight Tasks, Normal Operations, Recoverable Faults	Mission Operations	Simple Flight Plan, Simple Flight Tasks, Normal Operations, Recoverable Faults	Mission Operations	Simple Flight Plan, Complex Flight Tasks, Normal Operations, Recoverable Faults
Autonomy	Flight Stability	Autonomy	Navigation and Collision Avoidance	Autonomy	Navigation and Collision Avoidance
Decision-Making	Control-Level, Task-Level	Decision-Making	Task-Level, Fault-Level, Control-Level	Decision-Making	Task-Level, Fault-Level, Control-Level
Mission Fault	Expected, Internal, Correctable	Mission Fault	Expected, External, Correctable	Mission Fault	Expected, External, Correctable

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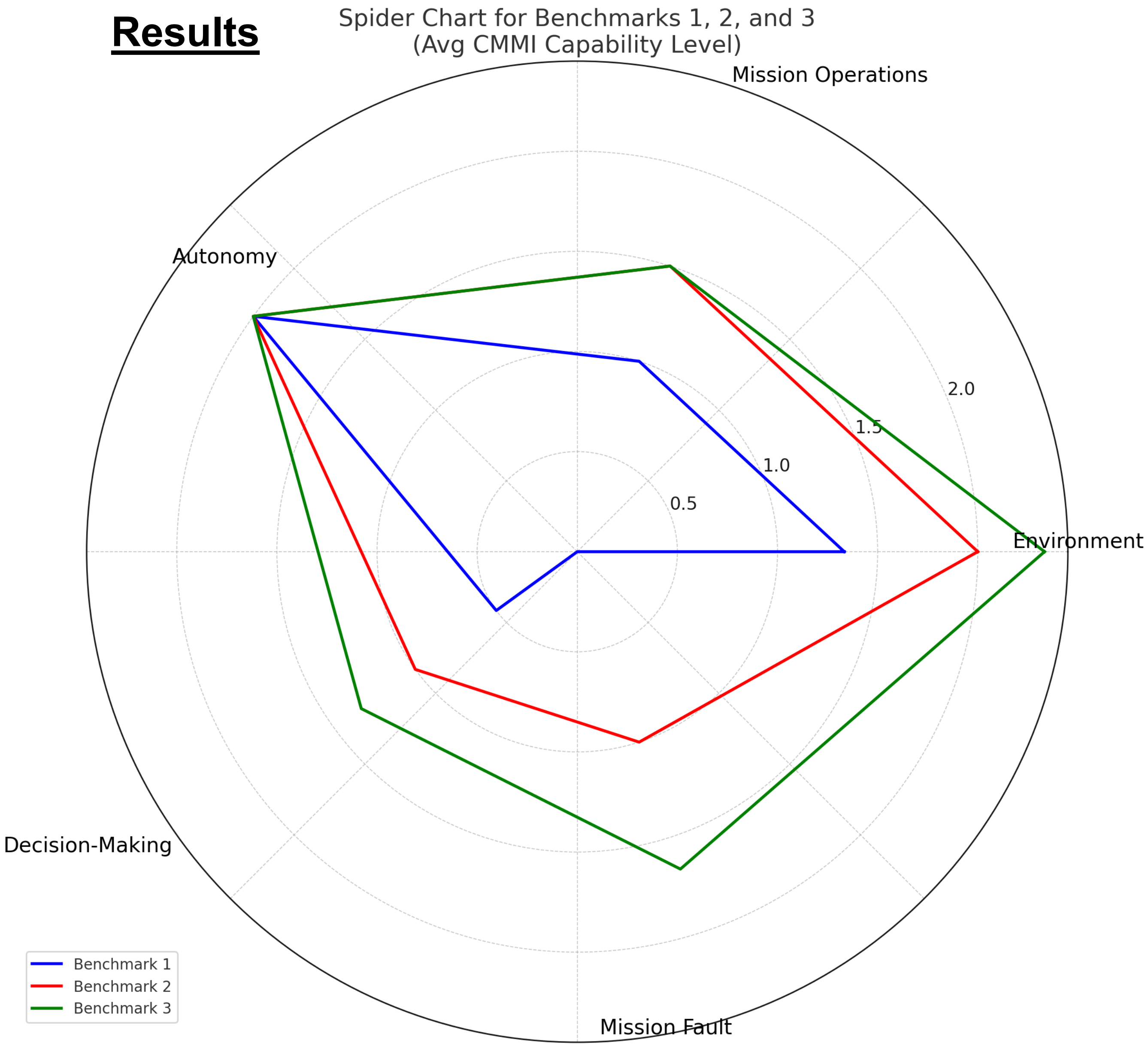

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UL 4600 Assessment

UL 4600 Case Evidence

CMMI-DEV Assessment

Measure UAM Capability and Organizational Maturity Criteria over time

Measuring Risk Acceptability

How much risk would I be willing to accept from a mission flown under this UAM Framework?

Approach:

1. Develop CMMI-DEV Process Groups along the lines of these categories for UAM
2. Assess using Staged CMMI Maturity model

Contingency Management	*Mission Success*	*Operations*
Inadequate	Vague	Reactive
Feasible	Post-Analysis	Basic Monitoring
Well-Planned	Scenario-Based	Systematic
Human Comparable	Conditional	Predictive
Fully Explainable	Attainable	Adaptive and Innovative

Mission Redefinition	*Environment (Area/Population/Weather Resilience)*		
Rigid	Deserted	None	None
Algorithm Modifiable	Rural	Low	Low
Human Modifiable	Suburban	Low-Medium	Medium
Human+AI Modifiable	Urban	Medium	High
AI-Modifiable	Emergency	Extremely High	Extremely High

Analysis Results

How much risk am I willing to accept for a mission under this UAM Framework?

Mission Risk Acceptability Category	CMMI-DEV Process Area	Maturity Level	Significance
Contingency Management	CM PMC	Level 2	Ensures robust contingency plans and risk mitigation strategies for effective response to unexpected events.
	RSKM	Level 3	
Environment	MA REQM	Level 2	Involves managing the impact of environmental factors on UAM operations.
	PI RD TS	Level 3	
	CAR	Level 5	
Mission Redefinition	DAR IPM RSKM	Level 3	Enables flexible adaptation and redefinition of mission parameters in changing conditions.
Mission Success	PMC PP REQM	Level 2	Focuses on managing mission requirements and project planning to achieve desired outcomes.
	RSKM	Level 3	
Operations	CM MA PPQA SAM	Level 2	Focuses on managing mission operational challenges, maintaining safety and flight quality standards.

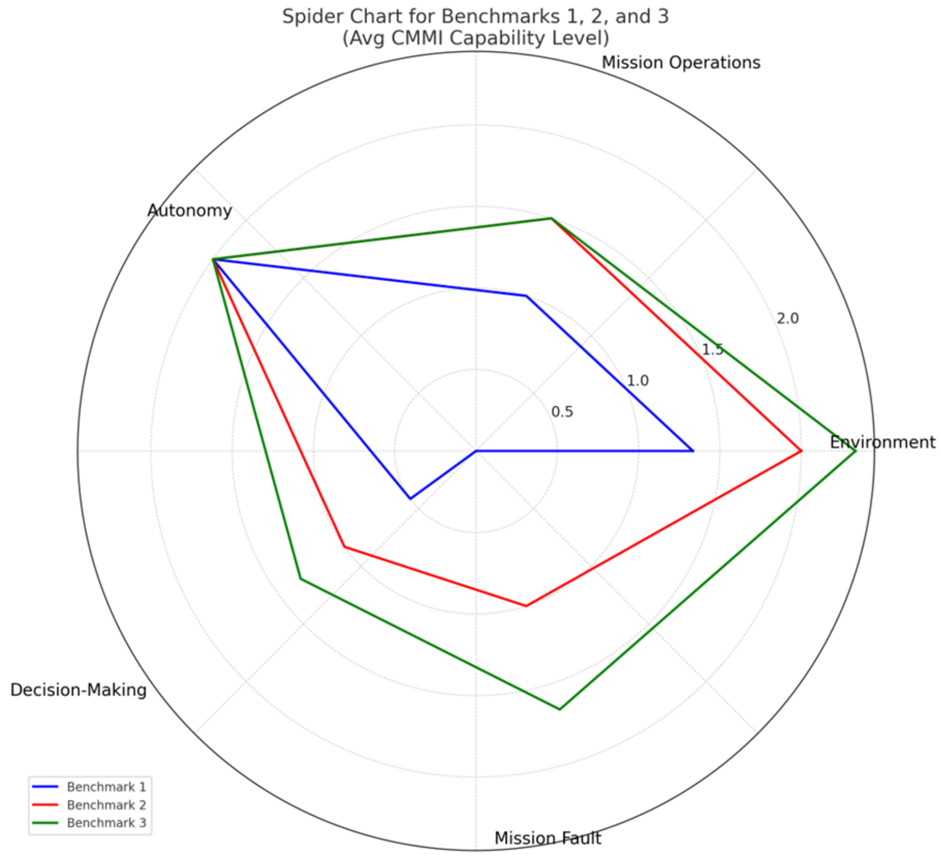
Mission Risk Acceptability Category	CMMI-DEV Process Area	SGs Met			SPs Met		
		Benchmark 1	Benchmark 2	Benchmark 3	Benchmark 1	Benchmark 2	Benchmark 3
Contingency Management	CM	2/3	2/3	2/3	5/7	6/7	6/7
	PMC	1/2	1/2	1/2	3/5	7/10	7/10
Environment	MA	1	1	1	1	1	1
	REQM	0	0	0	2/5	4/5	4/5
Mission Success	PMC	1/2	1/2	1/2	3/5	7/10	7/10
	PP	1/3	2/3	2/3	1/2	11/14	6/7
	REQM	0	0	0	2/5	4/5	4/5
Operations	CM	2/3	2/3	2/3	5/7	6/7	6/7
	MA	1	1	1	1	1	1
	PPQA	1/2	1/2	1/2	1/2	3/4	3/4
	SAM	1	1	1	1	1	1

Results

- Internal team CMMI-DEV assessment found these results, assuming the project as a whole is moving towards Maturity Level 2 (Managed)
- Project saw a rise in Specific Practices across the board
- Maturity of Mission Redefinition concerning CMMI-DEV is difficult to track until sub-project matures further

Conclusions

- Created an extendible method for tracking maturity of UAM Framework over subsequent exercises
- Leverage existing, reliable standards (Combined UL 4600 and CMMI-DEV) and related them to most recent UAM thinking
- Guidance for next steps when it comes to testing
- **Next Step:** Which categories do we need to mature? Which do we need to mature?



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